Mr. Johnstone.

The inspectors directed each cultivator in the watering, cleaning, and picking of the cotton-crop, and made him maintain sanitary conditions in his water-channels where mosquitos might breed, and clear out his water-channels each year. They advanced money to the cultivators during the period of the growth of the cotton. They operated a light railway for the transport of the cotton to the ginning-factories, and ginned, exported, and marketed the cotton, paid the cultivator on the proceeds of each individual out-turn, and generally cared for the cultivator.

Correspondence.

Mr. Grabham.

Mr. G. W. Grabham observed that Mr. Johnstone had referred to the geological formation of the Gezira plain. Igneous and metamorphic rocks, including bands of crystalline limestone, underlay the soil and subsoil on the west and south-west sides of the plain, and formed the base on which rested the Nubian Sandstone (Cretaceous). After the deposition of the Nubian Sandstone, the region had been subject to denudation for a long period, and a great deal of the sand stone had been removed, so that now the principal mass remaining within the Gezira was that forming the low ridge included within the 415-metre contour. The Nubian Sandstone also existed beneath the northern and eastern part of the area, but it was covered by later deposits. After the period of denudation there had arisen a system of streams draining, like the present ones, from the south east. They had flowed in a valley on the eastern side of the sandstone ridge and debouched northwards and westwards from it, forming a delta extending across to where the White Nile now lay and northwards as far as Khartoum. After the formation of that inland delta, a blanket of loess, or wind-deposited soil, had been laid down over the alluvial deposits. The material of that loess was not the sand that was rolled along on the surface and caught by the bushes, and formed dunes on the desert's edge. It was composed of the fine dust that was raised into the air and carried far afield, gradually settling among the vegetation in the more favoured regions some distance south of the desert. It contained relatively little quartz, and a good deal of lime and alumina, and it formed a very heavy and impermeable clay soil. Owing to the manner of its deposition and its even thickness, the surface of the loess exhibited the topography of the deltaic alluvial deposits on which it rested. The Blue Nile, as it was known to-day, was a relatively modern stream which had cut its well-defined valley into the loess and older alluvial deposits. Along the banks were narrow strips of alluvial

Mr. Grabham. soil, both fertile and easily irrigated by appliances within the means of peasants. Near the rivers, and in certain areas of the Gezira, there were belts of sand-dunes and sand-accumulations, and it seemed probable that that sand had come from the Blue Nile. During the low-stage season sand-banks were exposed along the channel and the dry sand was blown out up on to the river-banks by the prevalent north and north-east winds. It traversed the plain until it was caught by vegetation. An essential feature of the topography of the region was the very flat slope of the White Nile as compared with the Blue Nile. The flood-level of the Blue Nile at Sennar was about 38 metres above that of the White Nile in the same latitude. The valley of the Blue Nile extended only 2 or 3 miles west of the river, and from that point the surface of the Gezira plain, for the most part, sloped towards the White Nile. The principal exception to the general slope was the sandstone area in the south. Besides the rivers, water-supplies were derived from wells in both the sandstone and the alluvial deposits. The country where such deposits were absent, and where the loess soil rested directly on the crystalline rocks was not usually favourable for wells. The consequence was that the population had concentrated on the sandstone and alluvial regions. The influence of geological formations in that manner was very striking. Since the examination of the Blue Nile bed by Mr. S. C. Dunn and Mr. Grabham early in 1910, for the purpose of indicating places where foundation-conditions would be favourable for the construction of a dam, a good deal of attention had been devoted to the geology of the region. The dam at Sennar might be regarded as a coping on a bar of hard igneous rock, gabbro or teschenite, existing in the river-bed and intrusive in the Nubian Sandstone. Only a small part of the building-stone could be obtained on the site; but excellent granitic gneiss for rubble was obtained at Gebel Moya, while the granite at Gebel Seggadi proved suitable for ashlar. At the cement-factory the metamorphic limestone from Meshata, near Seggadi, was used, while the loess clay supplied the other principal ingredient. The loess, however, contained concretions of carbonate of lime, which spoilt it for ordinary brick-making. The material required for that purpose was supplied by the alluvial earths near the Blue Nile, which were also burnt to produce the homra that was mixed to produce the red cement used in the masonry of the dam and regulators. Mr. Johnstone mentioned the problem of securing good foundations on the loess clay, which expanded considerably on being wetted. Under natural conditions the surface layers of the loess soil might become saturated during the rainy season. Subsequently it dried, and the lateral shrinkage was shown by deep vertical cracks. It also shrank

Mr. Grabham

vertically, and, though that movement was considerable, it only became obvious in masonry buildings with ordinary foundations or when bench-marks were checked. Shallow foundations might be considerably protected by surrounding the buildings with wide ramps of soil to throw off the rain-water and so guard the soil near the foundations from extreme changes in moisture-content. Foundations of important structures should be carried to a depth of at least 2 metres so as to base them on soil below the limits of surface cracking. The problem of reliable bench-marks had been realized in the early stages of the scheme, and steel screw-piles about $2\frac{1}{2}$ metres long, or, exceptionally, 5 metres long, had been adopted for the purpose of reference-points at intervals of 2 kilometres along the traverse near the railway-line. The soil had proved to be so hard that the piles could not be screwed home. Pits had had to be dug, and, if the piles could be screwed a few inches into the bottoms of the pits before the soil was filled in again, it was the best that could be done. The matter had been referred to the Geological Survey, and, as a result, bench-marks had been put into the brick linings of wells at the railway-stations. Those linings reached depths of 18 to 30 metres, and it seemed unlikely that they could be affected by movements of the surface layers of the soil. Much of the early levelling had been done by the Egyptian Survey Department. He had been informed that, since the Sudan Survey Department had taken up the work, steel tubes with closed tops and base-plates about 30 centimetres square had been adopted for the purpose of establishing bench-marks. A pit was dug nearly 2 metres deep, the bench-mark tube was inserted with the base resting on undisturbed soil, and the pit was filled with well-rammed earth. He understood that none of the bench-marks had proved absolutely reliable. Relative movements of several centimetres had been found between marks. Until it was possible to undertake systematic relevelling, the exact amounts of movement would not be known. That matter was an example of one of the difficulties facing the engineer in setting out the scheme. The special properties of the loess clay had, however, contributed directly to the canalization scheme. Its impermeability allowed the canals to carry water for long distances with remarkably little loss by seepage. During construction, small canals many kilometres in length led supplies to the mechanical excavators. The impermeability of the material also lent itself to the system of storing water in the canals during the night. Since the scheme came into operation, wells had been abandoned, not only within the scheme, but for several miles around. The people preferred to drive their herds several miles and to fetch water from a canal rather than draw it from wells 100 feet deep.

Mr. Home. Mr. HENRY HOME observed that Mr. Johnstone described the surface soil as generally consisting of loess, except for a sandstone ridge, and the deposit as of high clay-content and very impervious to water. It was stated that it cracked deeply, and expanded considerably when wetted, and that side slopes of channels would not stand at 1 to 1. These characteristics did not correspond at all with those of loess as recognized by the geologist. It was generally accepted that loess was a deposit formed by wind-transported material and was usually associated geographically with glaciated areas from which it had been derived. It was invariably silty, with a clay-content of between 15 and 30 per cent., and it neither puddled nor held water. The most distinctive feature of loess was its behaviour on exposure to weathering or erosion. Where other materials, such as sand and clay, were worn to fairly gentle slopes, the loess stood in nearly vertical faces, and shovel-marks in cuttings remained clear for years. The structure and mechanical composition of loess soils were especially favourable to the movements of soil moisture. There was a fairly ready downward gravitational movement of water, and, on the other hand, such soils were fairly retentive of moisture and allowed the upward capillary movement of water in dry weather. From the particulars given by Mr. Johnstone of the soil of the Gezira he would suggest that the formation was simply a water-deposited clay silt and not a loess deposit. From his description, too, it followed that in such a soil a tendency to waterlogging might be expected and that the formation of hardpan could only be avoided by very careful methods of tilling and working the land. A uniform deposit of silt on the land, as thick as the carrying-power of the irrigation water would give, was an essential factor. From that point of view the design of the sections of distributing-canals and especially their use as reservoirs for night storage might be open to criticism. It would be of interest if Mr. Johnstone would give the chemical analysis of the irrigation-water, and the soil analysis, and especially the p_H values.

Mr. Lewis. Mr. A. D. LEWIS observed that a fundamental feature of all distribution-systems was the strength of the leading stream at the field, coupled, of course, with the size of the beds. In view of the very flat slopes of the Gezira, it might be assumed that very large leading streams could be adopted with advantage, especially as leading did not take place by night. It appeared from the Paper, however, that comparatively small streams were employed. It would be interesting to learn what the usual size of stream actually was, and what factors had determined the size. One of the most interesting features of the system was the elimination of night watering, which was the bugbear of irrigators in countries (like

Mr. Lewis.

South Africa) where the slopes were steep; however, for purposes of economy in construction, and on account of the fear of waterlogging and alkali in the lands and silt-deposits in the canals, it generally had to be enforced, except in the early stages of a clear-water scheme when the full area was not developed. It was not clear from the Paper why night leading was impossible. The flat slopes would appear to favour it. On account of the unusually flat slopes and the peculiar banked distributaries necessary to gain command of the land, no great additional cost appeared to be involved. It was claimed that the increased quantity of silt deposited on account of the heading up at night had the advantage of providing material for the repair of banks; but the scraping of shallow deposits of silt for long distances might prove expensive, and it would be interesting to learn whether the silt deposited in those flat canals, which must be very fine, was suitable for the formation of banks. The most serious aspect of wide, raised canals and the absence of drains was the fear of waterlogging and alkali trouble in the land. The seepage losses from the canals would be greater under such a system than under a normal system. Had the actual losses exceeded the assumptions made in the design? If the losses could be given per unit area of wetted surface, it would be easier to make comparisons with other systems. Reliance appeared to be placed on beds of water-laid sand and gravel underlying the clay to provide drainage. In view of the very flat slopes along which the deposits were made, one would like to be assured that the beds of sand and gravel were sufficiently continuous and capable of providing such drainage as would keep the water-table low. The chemical characteristics of the soil to be irrigated had not been dealt with in Mr. Johnstone's Paper. In regions of light rainfall and intense evaporation from heavy soils, alkali was generally a menace. In connection with the storage of grain there was mention of "salty ground" which at once aroused suspicion; and some information as to the alkali-content of the soil would be interesting, especially in view of the absence of drains. It seemed that a drainage-system would ultimately be required and that the natural direction of the main drains should be towards the White Nile. If that was so, then no free-flowing drainage would apparently be possible until the drains reached the neighbourhood of the White Nile, and he wondered why the process of gradual development was not in strips of complete units in that direction rather than parallel with the Blue Nile. He sympathized very heartily with the designers of every scheme where, on account of paucity of population, uncertainty as to water agreements, and other difficulties, the whole development could not be completed at the outset, Mr. Lewis. especially when comparatively large sums were spent on the headworks.

Mr. Johnstone. Mr. JOHNSTONE, in reply, observed that the physical and chemical properties of the Gezira soil had been the subject of investigation by the staff of the Wellcome Tropical Research Laboratories, who had installed laboratories at Wad Medani near the centre of the Gezira. The soil of the Gezira was described as a brown heavy clay, rather high in water-soluble salts, and possessing considerable alkalinity. The average composition of the soil for the first 4 feet at the Gezira research farm, a fair average for the Gezira, was stated[1] to be :—

	Per Cent.
Stones and gravel	2·1
Coarse sand	6·7
Fine sand	20·7
Silt	13·0
Clay	57·5
Salts	0·199

Calcium carbonate was present in two entirely different forms : the small black nodules which made up 80 per cent. of the stones and gravel, and white particles, some of which were shell-fragments, comprising about 80 per cent. of the coarse sand. The soil was extremely dense and hard and could be excavated by hand only with a pick. The earth would stand with a vertical face for a considerable depth, though occasionally a section of the face might fall off, showing a definite greasy face where the cleavage had occurred. The earth naturally cracked when dried and became friable on the surface when exposed to atmospheric action, with the result that the side slopes of the larger canals had been eroded at the water's edge and above the water in part by wave-action and in part by weathering and rain. In order to minimize this erosion later canals had been dug to 2 to 1 side slopes. The mineral composition of the soil for the typical first-foot sample was given[1] as :—

	Per Cent.
Silica (SiO_2)	48·28
Alumina (Al_2O_3)	14·97
Iron Oxide (Fe_2O_3)	9·91
Titanium Oxide (TiO_2)	2·31
Manganese Oxide (MnO)	0·28
Lime (CaO)	7·33
Magnesia (MgO)	1·37
Potash (K_2O)	0·31
Soda (Na_2O)	0·41
Phosphoric Oxide (P_2O_5)	0·12
Carbonic Acid (CO_2)	4·71
Volatile Matter (H_2O etc.)	9·44

[1] A. F. Joseph, "Alkali Investigations in the Sudan." *Journal of Agricultural Science*, vol. xv (1925).

Mr. Johnstone.

Examination of the soil profile showed zones where white particles of calcium were frequent, and at a depth of 4·6 feet aggregations of well-defined crystals of gypsum were common. The quantity of organic matter was small, the humus content being about 0·5 per cent. This was slightly higher in the third and fourth feet than in the first 2 feet. The following results were obtained from an examination of the soil of the Gezira research farm[1] :—

SUCCESSIVE 6-INCH STEPS.

Step	1	2	3	4	5	6	7	8	9	10	11	12
Salts : per cent.	0·07	0·08	0·09	0·11	0·16	0·43	0·49	0·43	0·54	0·65	0·65	0·61
Gypsum : per cent.	0·0	0·0	0 0	0·0	0·0	0·3	0·4	0·2	0·9	1·5	1·0	1·1
pH	9·44	9·51	9·53	9·59	9·49	9·10	8·89	9·14	8·95	8·76	8·74	8·81
Capillary rise : mm. in 5 hours	86	38	33	17	25	108	93	40	67	87	72	79

Observations made by the Chemical Section of the Wellcome Research Laboratories had not disclosed any appreciable increase of moisture in the deeper layers of the soil below 3 feet at the Gezira research farm[1]. The soil was exceedingly impermeable, and under ordinary conditions water did not penetrate beyond the limit of cracks in the soil—on an average 3 feet. At that level the salts were high, and there was a more or less defined band of greyish hard soil. That condition was assumed to occur at the base of the cracked soil and to be due to rain penetrating to that level and washing down humus and salts. The grey band was the natural condition of the soil before irrigation had been applied. It occurred generally nearer to the surface in the north, where the rains were light, than in the south where rains were markedly heavier and more frequent. Subsoiling in the areas where the grey band was high had been tried and had resulted in a rise of the surface-level after watering. However, the system of irrigation provided that one-third of the whole area should lie fallow for a whole year, and that the remaining area should lie fallow for periods ranging from 3 to 8 months. That provision, in conjunction with the very dense nature of the soil, would probably render deep drainage ineffective ; but, should it be found desirable or necessary at some later date to establish a drainage-system for either surface or deep drainage, the layout of the canal system was such as would allow for an efficient drainage-system.

[1] H. Greene, "Soil Profile in the Eastern Gezireh." *Journal of Agricultural Science*, vol. xviii (1928).

Mr. Johnstone. No experiments had yet been made to ascertain the loss by seepage, but, judging from superficial observation of minor distributaries, the loss was extremely local. In practice the carrying-losses in the larger canals had not been found to exceed the variation in the measurement of water.

So far the work carried out for formation of banks with soil excavated from the beds of minor distributaries had been quite satisfactory ; that earth, however, had not consisted entirely of silt, but of silt and the original loess mixed.

The average composition of monthly samples of Blue Nile water at Khartoum, taken from July to December, 1906, was as follows[1]:—

	In Water.	In Dissolved Solids.
	Parts per Million.	Parts per Million.
Suspended solids	689	..
Dissolved solids	115	..
Silica (SiO_2)	21·33	19·40
Chlorine (Cl)	1·69	1·54
Sulphur Trioxide (SO_3)	4·68	4·25
Carbon Dioxide (CO_2)	32·75	29·59
Lime (CaO)	27·34	24·85
Magnesia (MgO)	12·45	11·32
Soda (Na_2O)	6·56	5·96
Potash (K_2O)	2·75	2·52

The ratio of lime and magnesia to soda and potash was 4·3 to 1, which was usually considered very good. The alkalinity was not excessive, the average p_H value of four samples being 8·37 at 26°C.

[1] Dr. A. F. Joseph (*loc. cit.*), referring to a test of concentrating water by evaporation, says, "From a standpoint of irrigation therefore, the quality of water steadily deteriorates as concentration proceeds, the portion of lime at the final stage being insignificant. On the other hand the solution is so heavily buffered that the sixty fold concentration only results in doubling the hydroxylion concentration."